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Distribution System Reliability Evaluation Incorporating the Effect of Voltage Stability Index

D.K.Mohahta, M.Jaya Bharata Reddy, Abhishek Singh, Jayant Kumar Papneja, Shalabh Agarwal

***Abstract*—A distribution system is the system of an overall power system which links the bulk system to the individual customers. Reliability and Quality of supply(Voltage Stability) are important performance indices of a distribution system which need to be satisfied from customer point of view. This paper deals with calculation of both Reliability indices and Voltage Stability Index for a typical distribution system to analyze the optimum configuration.**

***Index Terms*— Distribution System, reliability, quality, voltage stability.**

I. Introduction

The proliferation of equipment and the basic structure results in a relatively high proportion of customer outages being associated with the distribution system[1].Data on utility failure statistics show that distribution system failures are approximately 80 percent of the total customer interruptions[2].Thus from the customers' point of view the reliability of distribution systems is at least as important as the reliability of generation and transmission.

Voltage stability is another important performance index which defines the quality of supply. Voltage in a transformer is expected to be constant from the customer point of view. In most of the analysis [3,4] either voltage stability or reliability along with minimized cost has been considered as the basis of distribution system planning.

A typical radial distribution system is considered and both reliability and VSI are calculated and assessed. The network is reconfigured and the new values of performance indices are calculated. Thus we have considered the distribution system reliability incorporating the effect of voltage stability index which gives a better insight to the requirement from the customers'.

II. Distribution System Performance Indices

Distribution networks are the parts of power systems that deliver energy from the area supply stations to the customers. They operate at several voltage levels (mostly from 11 kV to 33 kV in India), and often include the networks of local or municipal utilities[5].

A. Reliability Indices

1) Time Frequency Duration Indices

Failure frequency index $(f_F) = \sum C_{mn} \; f_{Fmn} / \sum C_{mn}$

Where the load point frequencies are weighed by C_{mn} , the number of customers on branch mn.

Mean system failure duration $(T_F) =$

$$\sum C_{mn} f_{Fmn} T_{Fmn} \;/\sum \; C_{mn} f_{Fmn}$$

Average total interruption time /customer / year $(H_F) =$

$$\sum C_{mn} f_{Fmn} T_{Fmn} /\sum C_{mn}$$

From the equation it is evident that

$$H_F = T_f f_f$$

It should be observed that the above indices are not based on any definition of what events constitute system failure, but are computed by arbitrarily chosen equations. The frequency f_{Fmn} for example is not the frequency of any given event but is an arbitrary measure of the system's performance[5].

2) Customer Load Point Indices

System Average Interruption Frequency Index (SAIFI) is the average number of interruptions of supply in the year for the customers who experience interruption of supply. SAIFI can be calculated mathematically as

SAIFI = Total no of customer interruptions/ Total no of customers served

$$= \sum \lambda_{Ni} \, Ni / \sum N_T$$

Where N_i is the number of customers in section or load point i, N_T represents the total number of customers on feeder λ_{Ni}.

System Average Interruption Duration Index(SAIDI) is the average total duration of interruptions of supply per annum that a customer experiences, for example

SAIDI=Total customer interruption duration/ Total no of customers served

$$= \sum Ui \; Ni / \sum Ni$$

U_i represents failure rate and down time of load point i.

Customer Average Interruption Duration Index(CAIDI) is the average duration of an interruption of supply in the year for customers who experience interruption of supply.

CAIDI= Total customer interruption duration/ Total no of customers interrupted

Dr. D. K. Mohanta, Mr. M. Jaya Bharata Redddy, Abhishek Singh, Jayant Kumar Papneja, Shalabh Agarwal. are with Electrical &Electronics Engineering Department, Birla Institute of Technology, Mesra, RANCHI-835215, India (E-mail: dkmohanta@bitmesra.ac.in).

$$=\sum U_i N_i / \sum \lambda N_i N_i$$

Where U_i is the outage time of the i^{th} load per year, Ni is the sum of customers at the i^{th} load point, and λ_i is the failure rate..

ASAI(Average Service Availability Index) = Customer hours of service demanded/ Customer hours of service available.[6]

B. VOLTAGE STABILITY INDEX

The voltage stability has been defined as the ability of a system to maintain voltage at all parts of the system so that with the increase of load ,both power and voltage are controllable[7].

The formula used for calculation of VSI is[7]:

$$VSI = 4[\,(X_{eq}P_{leq} - R_{eq}Q_{leq})^2 + X_{eq}Q_{eq} + R_{eq}P_{leq}]$$

Where,

$$R_{eq} = \Sigma P_{loss} / \{(P_{leq} + \Sigma P_{loss})^2 + (Q_{leq} + \Sigma Q_{loss})^2\}$$

$$X_{eq} = \Sigma Q_{loss} / \{(P_{leq} + \Sigma P_{loss})^2 + (Q_{leq} + \Sigma Q_{loss})^2\}$$

Where P_{leq} and Q_{leq} ae the total real and reactive loads.

III. CASE STUDY & RESULTS

A university campus is a typical distribution system with varying loads at different periods of a day. The distribution system of Birla Institute of Technology, Mesra comprises of 11 kV in coming feeders. The 11 kV/440 V transformers are situated at various sites.

The main problem encountered in BIT campus is the variation of loads at different transformers during various hours of the day. The main concentration of load during the morning hour is at the Institute building where large power is needed to supply the load demands of various classes, laboratories, library, offices etc . During this period the demand from various hostels is quiet low.

During the evening hours the maximum demand of power is from the quarters of the staff and hostels. A continuous supply should be there to cater to the demands of power for lighting the bulbs and tube lights, computers, fans. The use of some equipment, like heater, which consumes a lot of reactive power thereby causing a considerable drop in the supply voltage. So in order to ensure a consistent supply of voltage with considerable reliability we have to calculate the reliability indices and voltage stability index for various buses. The values of these indices for various feeders are calculated. Reconfiguration of the loads of the transformers is done in order to obtain an optimum configuration with better reliability indices and voltage stability index.

The line diagram of the full system is shown in Fig. 1.

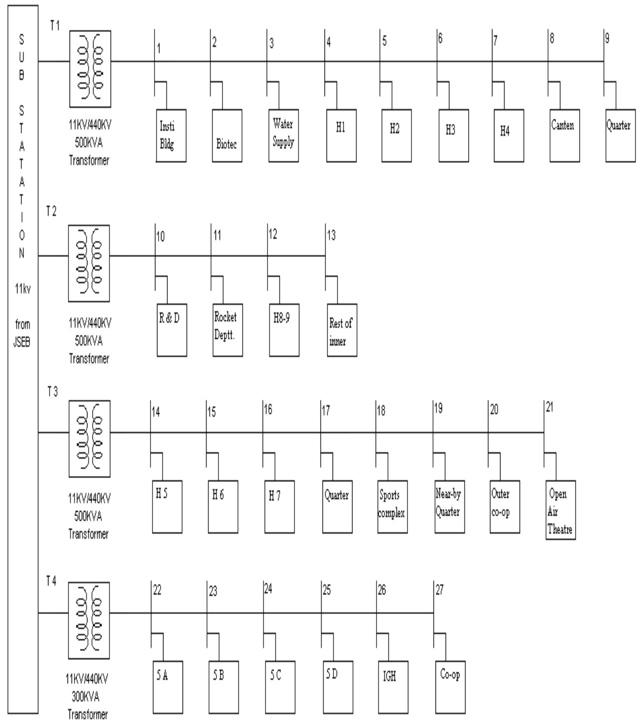

Fig. 1. Single line diagram showing the distribution system of the campus.

The transformer 1 of 500 kVA capacity supplies the loads as mentioned in Table-I.

TABLE I
TRANSFORMER I-500KVA

Description	Maximum connected load		
	KW	KVAR	KVA
Institute Building	646.29	484.7	807.86
Biotech Building	243.30	182.6	304.20
Water supply	146.51	90.73	172.33
Hostel 1,2,3,4	275	195	337.12
Canteen	100	75	125
Quarters(1&3)	69.9	118.73	137.8
Total	1481	1146.76	1872

The transformer 2 of 500 KVA capacity supplies the loads as mentioned in Table-II.

TABLE II
TRANSFORMER 2-500KVA

Description	Maximum connected load		
	KW	KVAR	KVA
R&D Building	300	249.2	390
Rocketry Dept.	200	150	250
Hostel 8&9	163.7	265	311.5
Inner Quarters	504	334.22	604.75
Total	1305.5	1069.1	1687

The transformer 3 of 500 KVA capacity supplies the loads as mentioned in Table-III.

TABLE III
TRANSFORMER 3-500KVA

Description	Maximum connected load		
	KW	KVAR	KVA
Hostel 5,6,7	451.52	277.14	529.52
Outer Quarter	483.5	362.622	604.4
Sports Complex	17	13.16	21.15
Outer canteen	10	7.5	12.5
OAT	75	66.14	100
Total	1036.62	726.28	1265

The transformer 4 of 300 KVA capacity supplies the loads as mentioned in Table-IV.

TABLE IV
TRANSFORMER 4-300KVA

Description	Maximum connected load		
	KW	KVAR	KVA
Hostel 5A	146.51	90.65	172.33
Hostel 5B	146.51	90.65	172.33
Hostel 5C	146.51	90.65	172.33
Hostel 5D	146.51	90.65	172.33
IGH+Dispensry	100	61.97	117.65
Total	686.04	425	806.97

An alternate modification of the above distribution system is shown in Fig. 2. We carry out the same analysis for the modified system.

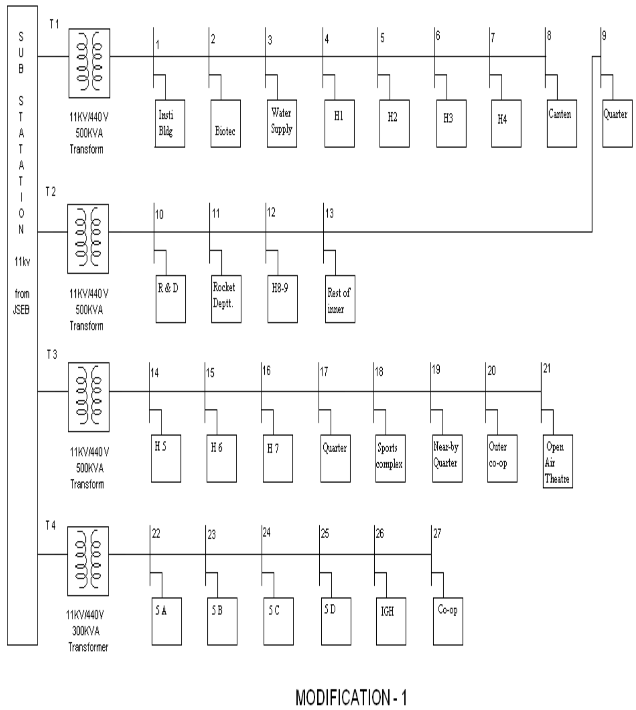

Fig 2. Modification of the distribution system

The new value of loads at various transformers are tabulated below:

TABLE V
NEW LOADS

Transformers	Calculated Data		
	KW	KVAR	KVA
G1(500 KVA)	1387	1086.76	1762
G2(500 KVA)	1399.5	1129.14	1798
G3(500 KVA)	1036.62	726.28	1265
G4(500 KVA)	686.04	425	807

By using the formulae defined above we calculate the values of reliability indices and voltage stability index for original and modified configurations both. Table-VI shows the VSI for both original and modified configuration.

TABLE VI
VSI

Transformer	VSI	
	Original	Modified-I
G1(500 KVA)	0.0021	0.00223
G2(500 KVA)	0.002345	0.0022
G3(500 KVA)	0.00307	0.00307
G4(500 KVA)	0.004	0.004
Overall system	0.002664	0.002685

Table VII compares the various reliability indices of both modified and original systems.

TABLE VII
RELIABILITY INDICES

Systems	Reliability Indices						
	F_F	T_f	H_f	SAIFI	SAIDI	CAIDI	ASAI
Original	0.174	5.308	0.922	0.174	4.99	28.75	0.9994
Modified	0.177	5.322	0.941	0.177	4.99	28.06	0.9994

From the above tables we can see that as the load on G1 decreases its VSI increases and that of G2 decreases. The VSI of the overall system is improved slightly and reliability indices decreases slightly.

The numerical values of the reliability indices and the voltage stability index (VSI) for the existing and modified or reconfigured systems show that there is a scope of improvement of the voltage stability i.e. the quality of supply but at the cost of reliability of the system.

IV. CONCLUSION

Optimal configuration of the distribution system can be obtained with acceptable values for both the indices. The compromise between quality and reliability has to be considered so that a stable and acceptable system is obtained. The optimization can be achieved by using various optimization techniques such as Genetic Algorithm, Tabu Search etc.

Thus the distribution system can be optimized for enhanced performance indices of which reliability and voltage stability are of prime concern.

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